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The influence of prestroke proficiency on poststroke lexical-semantic performance in bilingual aphasia

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Abstract

Background: Bilingual persons with aphasia (BWA) may present different degrees and patterns of impairment in their two languages. Previous research suggests that prestroke proficiency may be amongst the factors determining poststroke language impairment in BWA, however this relationship is not well understood.

Aims: The purpose of this study was to examine the relationship between prestroke proficiency and poststroke lexical-semantic performance in BWA and to identify common patterns of language impairment in this population.

Methods and procedures: Twenty-seven Spanish-English BWA (14 female, age range = 29–88 years) were administered a language use questionnaire (LUQ) to measure several aspects of their bilingual language history that contribute to their prestroke proficiency in both languages. They also underwent standardized language assessments tapping lexical-semantic performance in each language. A principal component analysis was first conducted on the LUQ metrics to determine the factors that contributed to prestroke proficiency in each language. Next, regression analyses allowed assessing the relationships between prestroke proficiency and poststroke lexical-semantic performance in both languages. Differences in proficiency and language performance across languages were contrasted prior and after stroke to identify profiles of impairment.

Outcomes and results: Prestroke proficiency in the native language was determined by daily use, educational history, lifetime exposure, and language ability rating. Prestroke proficiency in the second language was determined by age of acquisition, daily use, educational history, lifetime exposure, lifetime confidence, family proficiency, and language ability rating. Prestroke proficiency significantly predicted poststroke lexical-semantic performance in BWA in both languages. Twenty-two participants presented parallel impairment while only three presented differential impairment.

Conclusions: Our results confirm that prestroke language proficiency is a key predictor of poststroke language impairment in BWA. These findings have important implications for the assessment and diagnosis of aphasia in bilingual individuals.

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Disclosure statement

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Keywords

bilingual aphasia; prestroke proficiency; language impairment; lexical-semantic performance

1. Introduction

Current societies worldwide are increasingly becoming bilingual or multilingual as globalization and migration influence social changes that result in culturally heterogeneous populations with linguistically diverse interactions. However, given the sheer number of bilinguals in the world and the fact that the aging population is also on the rise, the incidence of aphasia in bilinguals due to stroke, closed head injury, or neurodegenerative disease is also expected to increase (Green, 2005) potentially becoming the majority of clinical cases (Fabbro, 2001; Paradis, 1998). In order to provide successful evidence-based intervention for bilingual persons with aphasia (BWA), it seems essential to better understand the factors that influence language processing in bilinguals and how they relate to language breakdown in the presence of brain damage. Similarly, determining common patterns of language impairment in BWA can help clinicians to better characterize the deficits revealed by formal language testing with consequent implications for the prognosis of recovery. Nevertheless, studies that have looked at language impairment in BWA are often case studies and frequently have not consider prestroke language ability as it relates to poststroke language impairment. Here, we aimed to determine whether prestroke language proficiency modulates poststroke language processing in the native (L1) and the second language (L2) in Spanish-English BWA and to characterize their patterns of language impairment.

In order to understand language impairment in bilinguals, it is crucial to consider the factors that influence bilingual language processing. Bilinguals can largely differ in the degree of competence for their two languages, the age at which they acquired their L2, their exposure to each language and the frequency of their usage. Therefore, it is reasonable to expect that differences in their language processing abilities reflect differences in crucial aspects of their bilingual language background. Importantly, research with healthy bilinguals suggests that language proficiency is a key determinant of lexical access and lexical-semantic processing (van Hell & Tanner, 2012). Specifically, past research has shown that (i) higher L2 proficiency is associated with better L2 performance whereas slower and less accurate L2 lexical retrieval is often observed in bilinguals with low L2 proficiency in both picture naming (Kohnert, Hernandez, & Bates, 1998; Kroll & Stewart, 1994) and verbal fluency (Blumenfeld, Bobb, & Marian, 2016; Sandoval, Gollan, Ferreira & Salmon, 2010), (ii) verbal fluency in L2 becomes comparable to that in L1 in balanced bilinguals with similar L1 and L2 proficiency (Roberts & Le Dorze, 1997), and (iii) highly proficient bilinguals also show faster resolution of lexical competition between L1 and L2 as compared to less proficient bilinguals (Blumenfeld & Marian, 2007). These findings suggest that bilinguals with low L2 proficiency show reduced L2 lexical access which may be associated with lower degree of automaticity and higher reliance on cognitive control mechanisms relative to highly proficient bilinguals (Abutalebi & Green, 2007; van Hell & Tanner, 2012). In line with this evidence, the Revised Hierarchical Model (Kroll & Stewart, 1994; Kroll, Van Hell, Tokowicz, & Green, 2010) suggests that the degree of L2 proficiency impacts the

organization of a bilingual's lexicon. The model assumes a common semantic system for word meanings and separate lexical systems for word forms across languages. In the model, active connections between L1 and L2 are asymmetrical such that in early L2 learning, L2 words are more strongly connected to their L1 translations than to the word concept, whereas L1 words are directly and more strongly connected to the word conceptual representation, as evidenced by slower translation from L1 to L2 than L2 to L1. As bilinguals become more proficient, lexical access to L2 is believed to happen increasingly via the concept of the word, and less via translation of the word from L2 to L1. Indeed, highly proficient bilinguals have direct access to word meaning from their two languages (Guasch, Sanchez-Casas, Ferre, & Garcia-Albea, 2011) and richer associations between L2 word forms and meanings could explain their faster and more effective L2 word retrieval relative to less proficient bilinguals (Kohnert, Bates & Hernandez, 1999; Kohnert et al., 1998). In this way, language proficiency can account for individual differences in lexical access in bilinguals.

L1 and L2 competence in bilinguals can be also influenced by the age and context of language acquisition and patterns of language exposure and use (Kohnert et al., 1998). Age of acquisition (AoA) and language exposure may account for differences in the representation of L1 and L2 in bilinguals (Peñaloza, Grasmann, Dekhtyar, Mikkuulainen, & Kiran, 2019). Moreover, L2 AoA can modulate lexical access as bilinguals with earlier L2 learning onset outperform bilinguals with later L2 AoA in word retrieval tasks (Bethlehem, de Picciotto & Watt, 2003; Poreh & Schweiger, 2002; Rosselli et al., 2000). Thus, L2 AoA may confer a facilitatory or detrimental influence on the degree of L2 mastery (Birdsong, 2018) such that late L2 AoA and lower degrees of L2 exposure and usage are associated with less optimal language performance (Hernandez & Li, 2007; Kastenbaum et al., 2018). Although past research has attempted to examine how these factors independently modulate bilingual language processing, language proficiency may reflect their joint contribution. Overall, the evidence that age and context in which L2 is acquired impact the way in which L1 and L2 are represented, accessed and processed in the bilingual brain (Abutalebi & Weekes, 2014; Kroll & Tocowicz, 2005), suggests that prestroke language acquisition, use, and exposure can be crucial in determining poststroke impairment in BWA.

Indeed, recent research has shown that self-rating scores of prestroke language proficiency can predict poststroke language performance in comprehension and production tasks in BWA (Gray & Kiran, 2013; Kiran, Balachandran & Lucas, 2014) and different patterns of impairment have been evidenced when taking into account prestroke proficiency and patterns of language use (Kiran & Iakupova, 2011; Muñoz & Marquardt, 2003). These findings provide preliminary evidence that prestroke L1 and L2 proficiency can influence poststroke deficits in L1 and L2 (Peñaloza & Kiran, 2019). Nonetheless, proficiency is a multidimensional construct (van Hell & Tanner, 2012) and self-ratings of proficiency can often reflect under or over-estimated ability (MacIntyre, Noels, & Clément, 1997). Thus, examining a broader consideration of how language history and use may contribute to relative proficiency and competence in each language may facilitate a more comprehensive understanding of how they relate to poststroke language performance in BWA.

Another important issue concerns the characterization of the patterns of impairment across the two languages spoken by BWA. Among all the patterns of deficits and recovery described in BWA (see Paradis, 2004 for a review), two patterns can be determined relative to premorbid proficiency: parallel and differential impairment (Gray & Kiran, 2013). Parallel impairment is determined when both languages are impaired to a similar degree whereas differential impairment indicates that one language is more impaired than the other (Fabbro, 2001; Kuzmina, Goral, Norvik, & Weekes, 2019). The first profile entails higher performance in one language versus the other consistent with premorbid proficiency, whereas the second involves higher performance in one language versus the other inconsistent with premorbid skill (Gray & Kiran, 2013; Muñoz & Marquardt, 2003). Past research has documented both parallel (Fabbro, 2001; Marangolo, Rizzi, Peran, Piras, & Sabatini, 2009; Watamori & Sasanuma, 1976) and differential impairment in BWA (Adrover-Roig et al., 2011; Fabbro, 2001; Junqué, Vendrell, Vendrell-Brucet, & Tobeña, 1989; Meinzer, Obleser, Flaisch, Eulitz, & Rockstroh, 2007). Although most studies have described their participants' patterns of deficits across languages, they have done so without fully considering comprehensive measures of factors that influence prestroke language proficiency. Only a few studies have examined the role that prestroke language history plays in language impairment in BWA. For instance, Tschirren et al. (2011) examined the effects of late L2 AoA on syntactic impairment in 12 BWA and found that although L1 and L2 aphasia severity suggested similar impairment across languages, four BWA presented with larger syntactic impairment in L2 relative to L1. Muñoz and Marquardt (2003) described the poststroke profiles of 4 Spanish-English BWA in relation to their prestroke language history using a questionnaire of language use, experience, proficiency, and literacy. They found three profiles of impairment: higher scores in one language relative to the other consistent with premorbid skill, higher scores in one language relative to the other inconsistent with premorbid skill, and variable performance inconsistent with premorbid skill. Similarly, Gray and Kiran (2013) examined the association between prestroke proficiency and poststroke language deficits in 19 Spanish-English BWA. Their findings revealed only parallel and differential impairment (compared to other patterns of deficits in BWA, Paradis, 2004) when comparing individual metrics of prestroke proficiency and poststroke performance on comprehension and production measures in each language. Altogether, these findings suggest that examining prestroke language proficiency can help understand poststroke patterns of bilingual language breakdown following brain damage.

In the present study, we aimed to extend the work of Gray and Kiran (2013) by examining whether prestroke language proficiency predicts poststroke lexical-semantic performance in a larger sample including 27 Spanish-English BWA. Importantly, Gray and Kiran (2013) considered self-reported ability ratings in each language as an index of prestroke proficiency and found that this metric predicted language impairment in BWA. In the current study however, we first sought to identify the factors in the language history of BWA that play a crucial role in determining prestroke proficiency in each language separately. Based on past research, we expected to find a positive association between prestroke proficiency and poststroke language performance, with prestroke language exposure, usage and AoA being the primary factors that contribute to prestroke language proficiency in BWA. Secondly, we aimed to determine the patterns of poststroke language impairment in BWA. As in Gray and

Kiran (2013), we expected to find parallel and differential impairment across the population, both of which reflect different levels of prestroke proficiency.

2. Materials and Methods

2.1 Participants

Participants were 27 Spanish–English BWA (14 female) whose language assessment and bilingual language history data reported here were retrieved retrospectively from a participant database in the Aphasia Research Laboratory at Boston University. Seventeen participants were previously reported in Gray and Kiran (2013). The data of nine of these seventeen participants were collected at time-points that differed from those reported in the previous study because their data, as reported here, were more recently acquired.

Participants' mean age was 54.85 years ($SD = 16.52$, range = 29–88) and their mean time poststroke was 31.96 months ($SD = 42.88$, range = 3–171). L1 was Spanish for 23 participants and English for 4 participants. All participants were literate in their L1 and reported varying degrees of L2 reading and writing ability prior to their stroke (only P8, P9, P11, and P15 indicated L2 reading and writing abilities at the single word level while showing additional evidence of being bilingual prior to their stroke). All participants had a primary diagnosis of aphasia subsequent to a left hemisphere stroke and were required to be at least 3 months poststroke onset at the time of assessment (Table 1). Participants provided their written consent for standardized language testing in accordance with procedures approved by the Ethical Committee of Boston University and the University of Texas at Austin.

2.2. Bilingual language background assessment

All participants completed a Language Use Questionnaire (LUQ) validated in healthy bilinguals with various language combinations (Kastenbaum et al., 2018). First, the LUQ allowed determining whether English or Spanish was the native (L1) or the second language (L2) for each participant. The next sections of the LUQ allowed obtaining the following prestroke language metrics: the AoA for the language identified as L2, and lifetime exposure, lifetime confidence, daily use, family proficiency, educational history, and self-rating of language ability for both English and Spanish separately (Table 2). *AoA* was measured as the age at which participants began to acquire the language that they reported as their L2. *Lifetime exposure* indicated the percentage of time (in 25% increments) that participants heard, spoke, and read each language over the course of their life (i.e., across three year intervals from age 0 to 3 and a final age interval for 30 and up). The percentages were averaged across all age intervals with a weight adjustment for participants over age 30, resulting in a lifetime English exposure score and a lifetime Spanish exposure score. *Lifetime confidence* reflected the participants' self-reported percentage of confidence (in 25% increments) in hearing, speaking, and reading each language over the course of their life (i.e., in three year intervals from age 3 through 30 years and up). Similar to *lifetime exposure*, the percentages were averaged across all age intervals with a weight adjustment for participants over age 30, resulting in a lifetime confidence score for English and Spanish. *Daily use* measured the languages participants and their conversation partners used on an

hourly basis for weekdays and weekends separately. The percentage of overall time participants and their partners spent using each language on both weekdays and weekends was calculated, resulting in two scores: daily use of English and daily use of Spanish. *Family proficiency* reflected the participants' ratings on their mother, father and siblings' proficiency in each language using a percentage scale: not confident (0%), 25% confident, 50% confident, 75% confident, and strong confident (100%). Average percentages of confidence were calculated resulting in one score of overall family proficiency for each language. *Educational history* evaluated whether Spanish, English or both languages were used at school at each level of education: elementary school, high school, and college. Participants also reported the language they preferred to speak and the language spoken by peers at school at each educational level. A percentage of education in each language was then calculated. *Language ability rating* represented the participants' self-rated prestroke language ability in Spanish and English based on a 5-point scale, with 1 being non-fluent and 5 being native fluency. Participants rated their ability to speak in casual conversations, listen in casual conversations, speak in formal situations, listen in formal situations, read, and write in each language and they also provided a self-rated score of prestroke overall fluency in each language. An average language ability score was then calculated for each language.

2.3. Standardized language assessments.

All participants underwent standardized language assessments to measure their poststroke abilities in both Spanish and English (Table 3). Naming ability was evaluated using the Spanish and English versions of the Boston Naming Test (BNT; Kaplan, Goodglass & Weintraub, 2001; Kohnert et al., 1998). Comprehension of spoken words in both languages was assessed using the semantic categories, synonyms, antonyms, and antonyms II subtests of the Bilingual Aphasia Test (BAT; Paradis, & Ardila, 1989; Paradis, Hummel & Libben, 1987) which were averaged into a BAT composite score. Non-verbal semantic knowledge was evaluated with the picture modality of the Pyramids and Palm Trees Test (PAPT, Howard & Patterson, 1992). Three participants (i.e., P1, P3, and P21) had incomplete language testing when they filled out the LUQ, hence, their language assessment data were retrieved from language assessment time points closest to the date of the participants' LUQ included for statistical analysis.

2.4 Statistical Analysis

Statistical analyses were performed using the R Statistical Software (R Foundation for Statistical Computing, Vienna, Austria). First and prior to all statistical analyses, multivariate imputation by chained equations was completed using the mice package in R to impute missing values (i.e., LUQ missing values for P3, P4, P10 and P15 and language assessment missing values for P4, P5, P12, and P15) with plausible data using predictive mean matching. Imputed data were individually contrasted against the participants' scores on other available measures to ensure that imputed values were reasonable for each participant's language proficiency or language abilities (Tables 2 and 3). In a second step, all LUQ and standardized language assessment data collected in English or Spanish were coded as being L1 or L2 for each participant as determined by the LUQ. Next, a principal component analysis (PCA) approach was used to reduce the large number of individual data

on all the variables included in the LUQ and the standardized assessments of language processing to underlying components measuring the same construct. The first PCA was performed separately for L1 and L2 across all LUQ metrics (i.e., lifetime exposure, lifetime confidence, daily use, family proficiency, educational history, and self-rating of language ability for L1 and L2 separately, and additionally AoA for just L2). The second PCA was performed separately for L1 and L2 across all language scores (i.e., BNT, BAT, and PAPT scores). Factor loadings were examined using a varimax normalized factor rotation. In all cases, factors with eigenvalues greater than 1 were determined to be principal components. Items with factor loadings greater than 0.5 were taken to load onto a particular factor and therefore were assumed to be highly correlated with that component. Following the first PCA, individual factor loading scores were extracted for each participant for L1 and L2 to represent the participants' prestroke L1 and L2 proficiency. The second PCA yielded individual factor loading scores that represented each participant's poststroke L1 and L2 overall language performance.

Finally, a linear regression analysis was conducted on the LUQ and language assessment factor loading scores to determine whether prestroke proficiency in L1 and L2 predicted poststroke L1 and L2 language performance respectively in BWA. Given that L1 was English for some participants and Spanish for others, L1 language was included as an additional categorical factor in these analyses. The first linear regression used L1 proficiency, L1 language and their interaction to predict L1 language performance. The second linear regression used L2 proficiency, L1 language and their interaction to predict L2 language performance.

To address the second aim of the study (i.e., patterns of impairment), a composite score was separately generated for L1 and L2 proficiency for each BWA, by averaging the participant's values on the variables that loaded onto the first component of the PCA conducted on the LUQ data for each language. Similarly, a composite score was separately computed for L1 and L2 poststroke lexical-semantic performance for each participant by averaging the participants' scores on the BNT, BAT, and PAPT in L1 and L2. Note that although derived from different sources and measured in different units, the proficiency and lexical-semantic performance composite scores served as proxies of individual ability in L1 and L2 prior and after stroke to determine patterns of impairment across languages relative to premorbid proficiency as defined in previous research (Gray & Kiran, 2013; Lorenzen & Murray, 2008; Muñoz & Marquardt, 2003). Parallel impairment was determined when scores on prestroke proficiency and poststroke language performance in one language were numerically greater than those observed in the other language. In other words, differences in poststroke ability across languages remained consistent with premorbid skill (e.g., L1 was dominant before stroke and remained dominant after stroke). Differential impairment was identified when prestroke proficiency scores in one language were numerically greater (or lower) relative to the other language but poststroke language performance scores were numerically lower (or greater) relative to the other language. Hence, this profile showed a reversed pattern of differences across languages after stroke inconsistent with premorbid skill (e.g., L1 was dominant before stroke, L2 became dominant after stroke). Two participants were excluded from this analysis because of incomplete proficiency data (i.e., P4) or L2 standardized language testing data (i.e., P15).

3. Results

3.1. Relationship between prestroke language proficiency and poststroke lexical semantic performance in BWA

The PCA performed with the L1 scores of the LUQ revealed one component with an eigenvalue greater than 1 explaining 52.96% of the variance in the L1 LUQ data. The LUQ L1 scores loading onto this component included: daily use, educational history, lifetime exposure, and language ability rating as factors that contribute to the prestroke L1 proficiency of the BWA. The PCA conducted on the L2 scores of the LUQ revealed one component with an eigenvalue greater than 1 explaining 71.14% of the variance in the LUQ data. All LUQ L2 scores loaded onto Component 1 indicating that all LUQ metrics are factors that contribute to the L2 prestroke proficiency of the BWA (Table 4).

The PCA on L1 standardized language assessment scores revealed one component with an eigenvalue greater than 1 and explained 71.80% of the variance in the L1 lexical-semantic performance of BWA. All L1 standardized language assessment measures loaded onto Component 1. Likewise, the PCA on L2 standardized language assessment scores revealed one component that had an eigenvalue greater than 1 and explained 74.94% of the variance in the L2 lexical-semantic performance of BWA. Again, all L2 standardized language assessment measures loaded onto Component 1 (Table 4).

The linear regression analysis conducted to determine if prestroke L1 proficiency predicts poststroke L1 lexical-semantic performance resulted in a significant best-fit model that explained 33% of the variance when taking into account L1 language (English vs. Spanish) ($R^2=.33$, $F(3,23)=3.77$, $p=.025$). L1 proficiency independently was a significant predictor of L1 lexical-semantic scores ($\beta=3.34$, $SE=1.17$, $t=2.85$, $p=.009$) whereas L1 language was not a significant predictor of L1 lexical-semantic performance ($\beta=1.37$, $SE=0.90$, $t=1.52$, $p=.14$). The interaction between L1 language and L1 prestroke proficiency was significant ($\beta=-3.29$, $SE=1.18$, $t=-2.78$, $p=.011$), suggesting that L1 proficiency was more predictive of L1 lexical-semantic performance in BWA with English as their L1 than in BWA for whom Spanish was their L1.

The linear regression analysis to determine if prestroke L2 proficiency predicted poststroke L2 lexical-semantic performance resulted in a significant best-fit model that explained 38% of the variance when taking into account L2 language ($R^2=.38$, $F(3,21)=4.2$, $p=.017$). L2 proficiency independently was a significant predictor of L2 lexical-semantic scores ($\beta=-1.44$, $SE=.77$, $t=-1.87$, $p=.075$), whereas L1 language was not a significant predictor of L2 lexical-semantic scores ($\beta=.21$, $SE=.46$, $t=.46$, $p=.65$). The interaction between L1 language and prestroke L2 proficiency was significant ($\beta=1.96$, $SE=.79$, $t=2.49$, $p=.021$), indicating that L2 proficiency was a better predictor of L2 lexical-semantic performance in BWA whose L2 was English than those for whom L2 was Spanish.

3.2. Patterns of language impairment in BWA

Two distinct profiles of language deficits emerged: parallel impairment and differential impairment (Figure 1). Twenty-two participants demonstrated higher poststroke lexical-semantic performance in their language with highest prestroke proficiency relative to the

other language, thus revealing a pattern of deficits consistent with a parallel impairment. Of these, 15 BWA showed greater ability for L1 relative to L2 whereas 7 participants showed greater ability for L2 relative to L1. As such, these participants reflect the same trends of language dominance before and after their stroke (e.g., if Spanish was dominant prestroke, Spanish remained dominant post-stroke). Only, three participants demonstrated a profile of deficits consistent with a differential impairment, in that their poststroke language performance was better in the language that they were less proficient before their stroke (e.g., if Spanish was dominant before stroke, English was dominant after stroke).

4. Discussion

The present study examined the role of prestroke proficiency in poststroke lexical-semantic performance in bilingual aphasia. Specifically, we looked at aspects of bilingual language history that determine prestroke L1 and L2 proficiency in 27 Spanish-English BWA, and how these factors predicted their poststroke performance on standardized language tests in both languages. In addition, we aimed to characterize the profiles of language impairment in BWA. Our findings revealed that, after accounting for L1 language (English vs. Spanish), L1 and L2 prestroke proficiency explained 33% and 38% of the variance in lexical-semantic processing in L1 and L2 in BWA respectively. These results indicate that prestroke L1 and L2 proficiency can directly impact the performance of BWA on standardized language assessments in both languages after stroke and support past evidence showing that the modulatory effect of proficiency on language processing in healthy bilinguals (Blumenfeld et al., 2016; Kohnert et al., 1998; Kroll & Stewart, 1994) remains true even after brain damage. This evidence is in line with previous research showing a positive association between prestroke proficiency and poststroke language outcomes in verbal comprehension and semantic processing (Gray & Kiran, 2013) and naming and word generation in BWA (Kiran et al., 2014) suggesting that premorbid proficiency can be a reliable determinant of lexical access and semantic processing both at the single word level and sentence level (see Khachatryan et al., 2016 for a review).

It has been suggested that language proficiency, which reflects the depth of encoding of linguistic knowledge of two different languages, is the major determinant of the differences observed in their recovery trajectory in bilinguals with post-stroke aphasia and lesions can degrade knowledge that is not deeply encoded to different extents (Nadeau, 2019). Nonetheless, given the limited variance in L1 and L2 lexical-semantic performance in each language that was explained by prestroke L1 and L2 proficiency, it is worth considering that other factors additionally account for poststroke language impairment in BWA. Indeed, individual variability in poststroke bilingual language performance may be also determined by interacting factors related to brain damage including aphasia type and severity, and lesion location and volume (Kiran & Roberts, 2012; Peñaloza & Kiran, 2019) and potentially by poststroke factors including L1 and L2 use and exposure (Ansaldi & Ghazi Zaidi, 2014). After stroke, language exposure and usage may change as a consequence of reduced availability of language rehabilitation in both languages and the social limitations of aphasia which may further influence impairment in one or both languages. While the LUQ allows obtaining information on post-stroke language exposure and usage, this information was available for only a few participants, hence we were unable to include these metrics in our

regression models. More research is clearly required to examine the joint contribution of prestroke language proficiency together with lesion factors and poststroke language-related factors to lexical-semantic deficits in BWA.

Our results also showed that prestroke proficiency was more predictive of poststroke lexical-semantic performance in BWA for L2 relative to L1. This finding may reflect the fact that the LUQ was able to capture a larger number of relevant factors that altogether significantly contributed to explain a larger variance of L2 relative to L1 prestroke proficiency (i.e., 71.14% for L2 relative to 52.96% for L1). A better capacity of the LUQ to account for L2 proficiency may have consequently increased its predictive power on poststroke L2 language performance. Also, LUQ metrics may allow for a better measurement of L2 as compared to L1 proficiency because bilingual speakers may possess more explicit knowledge on how their L2 was acquired and used in formal education settings and due to a later L2 exposure and immersion as compared to L1 which in great part is more implicitly acquired from very early on in life (Paradis, 2004; Ullman, 2004). Finally, larger individual variability can be expected in both the history of L2 acquisition and experience and L2 language performance relative to L1, especially in populations immersed in a second language environment with different amounts of L2 exposure and use, allowing for a better statistical examination of potential proficiency-performance associations.

The regression analyses also revealed that the associations between prestroke proficiency and poststroke language impairment in bilingual aphasia can be sensitive to the native language as evidenced by the significant interaction between L1 language and prestroke proficiency in L1 and L2. More specifically, we found that L1 prestroke proficiency was a better predictor of L1 lexical-semantic performance for BWA whose L1 was English, whereas L2 prestroke proficiency was a better predictor of L2 lexical-semantic performance for BWA whose L1 was Spanish (and L2 was English). This pattern was clearer when English was L1 or L2 relative to when Spanish was L1 or L2. This may be due, in part, to the fact that all participants were bilingual Spanish-English speakers living for varying amounts of time in the United States at the time of their completion of the LUQ and standardized language assessments. It is possible that the LUQ may not adequately capture Spanish proficiency in Spanish-English BWA who are native Spanish speakers with different degrees of language immersion in a predominant English speaking country. Likewise, it is possible that language performance in Spanish is less optimally evaluated in this population relative to English, as previous research with healthy Spanish-English bilinguals has shown that performance in standardized tests in Spanish can be underestimated (Gollan, Weissberger, Runnqvist, Montoya & Cera, 2012) or may lead to highly variable patterns of response as compared to tests administered in English (Kohnert et al., 1998). This observation is consistent with the results of Gray and Kiran (2013) showing similar discrepancies in the strength of correlations between prestroke proficiency and performance of BWA in English and Spanish standardized language tests and may reflect differences with regards to language immersion amongst other factors that make the Spanish-English bilingual population in the United States highly heterogeneous.

Importantly, our findings revealed that educational history, daily use, language ability rating and lifetime exposure contributed to L1 prestroke proficiency. In addition to these factors,

AoA, family proficiency, and lifetime confidence also contributed to L2 prestroke proficiency. These results support the view of language proficiency as a multifactorial construct (van Hell & Tanner, 2012) with different aspects of language learning history contributing to individual profiles of L1 and L2 prestroke proficiency in BWA. Previous studies, have typically measured prestroke proficiency in BWA using self-reported ratings that measure language abilities separately or as a single language competence metric (Kuzmina et al., 2019). However, self-reported measures may not always be accurate in reflecting objective proficiency. Our findings suggest that considering just one of these factors does not fully capture a person's prestroke proficiency, particularly for L2. This raises the concern that descriptions of language impairment in BWA in relation to just one aspect of their bilingual language background may only partially help understanding their language deficits, or even lead to potential errors in the interpretation of their prestroke language dominance and differences in poststroke performance across their languages. In contrast, obtaining multiple measures for each BWA may help increasing the accuracy in estimating individual prestroke competence for each language and may facilitate the detection of discrepancies in performance across languages.

The present study also allowed identifying two patterns of language impairment in BWA. Parallel impairment was the most common pattern of language impairment with 88% of the BWA included in this analysis displaying the same trend of dominance across languages before and after stroke (e.g., if Spanish was dominant prior to stroke, it remained dominant after stroke). Only 12% of the BWA demonstrated a pattern of differential impairment with a reversed trend of dominance across languages before and after stroke (e.g., if Spanish was dominant prior to stroke, English became dominant after stroke). Thus, our findings support previous research showing that parallel patterns of language impairment and recovery are the most common clinical outcome in BWA (Fabbro, 2001; Gray & Kiran, 2013; Paradis, 2001). The high frequency of occurrence of parallel impairment supports the critical role of prestroke proficiency in determining poststroke language status: language recovery in BWA depends on premorbid differences in L1 and L2 skills, and tends to be better for the strongest language before brain insult (Nadeau, 2019). Thus, higher premorbid proficiency in L1 relative to L2 may contribute to explain better poststroke performance in L1 relative to L2 in BWA (Kuzmina et al., 2019). Indeed, premorbid differences in L1 and L2 proficiency among other factors likely explain differential impairment and recovery profiles and differential impairment in early reported cases of bilingual aphasia may be at least partially attributed to underspecified assessments of premorbid proficiency (Peñaloza & Kiran, 2019).

Our findings have important clinical implications in terms of assessment and the prognosis of language recovery in BWA. While it is well known that standardized language assessments should be conducted in both languages in BWA (Paradis, 2004) our results support more recent recommendations on the importance of conducting such assessments together with comprehensive measures of bilingual language history that can inform clinicians on the prestroke language proficiency of a BWA in both languages (Centeno, Ghazi-Saidi, & Asaldo, 2016; Lorenzen & Murray, 2008; Peñaloza & Kiran, 2019; Siyambalapitiya & Davidson 2015). Detailed information on prestroke language proficiency may improve an otherwise limited understanding of language deficits in BWA, particularly when language proficiency differs across languages. For instance, evaluating language

deficits in the light of prestroke skills may help avoiding an erroneous overestimation of poststroke impairment in the prestroke non-dominant language. Furthermore, determining whether a BWA shows a parallel or differential pattern of impairment early after stroke may help making more accurate predictions regarding how one language may recover relative to the other language. A better understanding of the relationships between prestroke proficiency and language impairment may ultimately help guide decisions for treatment and to monitor progress across languages in therapy.

Despite the large sample size of this study, it is worth considering that only four BWA reported English as their L1. Future studies with a similar distribution of English and Spanish native speakers with aphasia will allow to further ensure that the relationships between prestroke proficiency and poststroke impairment observed in this study equally apply to Spanish-English BWA who have English as their native language. While our findings highlight the important role of prestroke proficiency on poststroke language performance, it is also possible that poststroke language use and exposure influence language impairment in BWA. Healthy immigrant speakers may display stronger language skills in their L2 relative to L1 due to L2 immersion (Hernandez, Bates, & Avila, 1996). After stroke, it is possible that BWA change their patterns of language exposure and use and rely more on their L1 to support basic communicative interactions with close relatives and caregivers, especially in BWA who acquired their L2 later in life and for whom the degree of disability restricts social interaction and continued L2 immersion. Future studies will need to examine whether changes in language exposure and use after stroke also contribute to language impairment in BWA. Finally, it is worth to acknowledge missing data as a limitation in the present study, since six participants did not have all LUQ and/ or language testing values, and the language assessments of three participants did not match the timepoints of LUQ completion. However, these limitations should not compromise our findings for the following reasons. In the first case, multivariate imputation by chained equations is thought to reliably estimate missing values from existing data. In the second, the time between LUQ and language test administration (i.e., maximum gap of 33 months) is not expected to influenced their association since the LUQ reflected the participants' bilingual language history only prior to their stroke in all cases, and language performance can be considered fairly stable within different yet relatively close time points over the chronic phase of brain insult.

5. Conclusions

Our findings indicate that prestroke language proficiency can directly impact L1 and L2 poststroke language impairment in BWA as revealed by standardized language assessments typically employed with bilingual populations. In line with previous research, we found that parallel and differential impairment are two common patterns of language dysfunction that may arise in BWA after stroke. Importantly, such patterns of language impairment indicate how languages in a bilingual speaker can be affected relative to their prestroke proficiency. Altogether, our findings provide further evidence for existing recommendations for clinicians working with bilinguals with aphasia: a detailed examination of different aspects in the prestroke language history of bilingual speakers that contribute to their attained

proficiency in their two languages can contribute to a better understanding of how L1 and L2 deficits manifest and recover after brain insult.

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Figure 1. Patterns of impairment in BWA.

Prestroke and poststroke ability are shown for each BWA: dark colored bars represent prestroke ability in L1 and L2, lighter colored bars depict poststroke ability in L1 and L2. Composite scores represent the average participant's values on the metrics that contributed to prestroke proficiency and post-stroke language impairment in the principal component analysis (PCA). Two patterns of language impairment were identified in the study: parallel impairment with either L1 poststroke ability being dominant relative to L2 consistent with prestroke ability (panel A) or L2 poststroke ability being dominant relative to L1 consistent with prestroke ability (panel B), and differential impairment with a reversed trend of ability across languages before and after stroke (e.g.: L1 prestroke ability was dominant relative to L2 but L2 poststroke ability was dominant relative to L1) (panel C).

Table 1.

Demographic characteristics of BWA.

Participant	Sex	Age	TPO	L1
P1	M	59	66	English
P2	F	64	152	Spanish
P3	F	58	15	Spanish
P4	M	59	9	Spanish
P5	F	53	8	Spanish
P6	M	53	11	Spanish
P7	F	73	29	Spanish
P8	M	75	50	Spanish
P9	F	85	7	Spanish
P10	F	88	9	Spanish
P11	M	41	3	Spanish
P12	F	41	3	Spanish
P13	M	43	83	Spanish
P14	M	36	171	Spanish
P15	F	77	4	Spanish
P16	F	65	5	Spanish
P17	M	76	12	Spanish
P18	F	33	3	Spanish
P19	M	54	16	Spanish
P20	F	48	6	Spanish
P21	M	31	27	Spanish
P22	M	33	12	English
P23	M	29	42	Spanish
P24	F	51	33	Spanish
P25	M	55	14	English
P26	F	49	17	Spanish
P27	F	52	56	English

TPO = Time post stroke onset (months); L1 = native language; M= male; F = female.

Table 2.

Summary of individual scores on the LUQ metrics for L1 and L2

BWA	L1							L2					
	Exp ^a	Conf ^b	Use ^a	Fam ^c	Educ ^a	LAR ^c	AoA	Exp ^a	Conf ^b	Use ^a	Fam ^c	Educ ^a	LAR ^c
P1	0.75	1.00	0.94	0.83	1.00	1.00	0	0.25	0.83	0.06	0.83	0.00	0.49
P2	0.55	1.00	0.50	1.00	1.00	1.00	21	0.45	0.67	0.50	0.25	0.00	1.00
P3	0.37	0.59	0.42	0.92	0.22	0.47 [*]	5	0.63	0.78	0.58	0.83	0.78	1.00 [*]
P4	1.00 [*]	0.94 [*]	0.45 [*]	0.92 [*]	0.06	0.67	0	NA	0.96 [*]	NA	0.00 [*]	0.94	0.81
P5	0.38	0.94	0.46	1.00	0.33	0.74	3	0.62	0.99	0.54	1.00	0.67	0.94
P6	0.34	0.66	0.45	1.00	0.42	1.00	6	0.66	0.96	0.55	0.67	0.58	1.00
P7	0.66	1.00	1.00	1.00	0.75	1.00	17	0.34	0.83	0.00	0.88	0.25	0.82
P8	0.97	0.51	0.84	1.00	1.00	1.00	28	0.03	0.08	0.16	0.08	0.00	0.10
P9	0.95	1.00	0.70	1.00	0.00	0.57	69	0.05	0.00	0.30	0.00	0.00	0.20
P10	0.29	1.00	0.01	1.00	0.00	0.74 [*]	5	0.71	1.00	0.99	1.00	1.00	1.00 [*]
P11	0.90	1.00	0.71	1.00	1.00	0.94	18	0.10	0.11	0.29	0.17	0.00	0.34
P12	0.68	1.00	0.71	1.00	0.78	0.94	9	0.32	0.41	0.29	0.33	0.22	0.66
P13	0.72	1.00	0.78	1.00	1.00	0.89	19	0.28	0.40	0.22	0.33	0.00	0.89
P14	0.26	1.00	0.34	1.00	0.00	0.47	6	0.74	0.81	0.66	0.67	1.00	1.00
P15	0.85	1.00	0.92	1.00	1.00	1.00	30	0.15	0.46 [*]	0.08	0.00	0.00	0.26
P16	0.87	1.00	0.98	1.00	1.00	1.00	45	0.13	0.13	0.02	0.00	0.00	0.29
P17	1.00	1.00	1.00	1.00	1.00	1.00	40	0.00	0.15	0.00	0.00	0.00	0.45
P18	0.71	1.00	0.54	0.92	0.72	1.00	12	0.29	0.52	0.46	0.67	0.28	0.80
P19	0.89	1.00	0.99	1.00	0.50	1.00	4	0.11	1.00	0.01	0.08	0.50	0.34
P20	0.45	1.00	0.50	1.00	0.67	1.00	5	0.55	0.45	0.50	0.75	0.33	0.80
P21	0.29	0.68	0.15	0.67	0.06	0.66	5	0.71	0.93	0.85	1.00	0.94	1.00
P22	0.91	1.00	1.00	1.00	1.00	1.00	11	0.09	0.50	0.00	0.25	0.00	0.80
P23	0.97	1.00	0.96	1.00	0.75	1.00	15	0.03	0.17	0.04	0.33	0.25	0.67
P24	0.23	0.20	0.50	1.00	0.25	0.74	7	0.77	0.96	0.50	0.67	0.75	1.00
P25	0.43	1.00	0.90	1.00	0.33	1.00	0	0.57	1.00	0.10	0.92	0.67	1.00
P26	0.59	1.00	0.22	1.00	0.78	0.99	12	0.41	0.46	0.78	0.17	0.22	1.00
P27	0.71	1.00	0.89	1.00	1.00	1.00	13	0.29	0.90	0.11	0.67	0.00	0.77

Scores are expressed as proportions of ^a time (for exposure, use and education history in L1 and L2), ^b confidence in L1 and L2, and ^c family and self-rated proficiency in L1 and L2.

* Proportion values estimated via multivariate imputation by chained equations using the MICE package in R. LUQ metrics on L2 use and exposure for P4 are marked as NA (not available) because plausible values could not be estimated using this procedure.

BWA = Bilingual person with aphasia; L1 = native language; L2 = second language; ID = participants identifier; Exp = lifetime exposure; Conf = lifetime confidence; Fam = family history; Educ = educational history; LAR = language ability rating; AoA = Age of acquisition (expressed in years).

Table 3.

Proportion of correct responses of BWA on language standardized tests on L1 and L2

BWA	Lexical-semantic processing in L1						Lexical-semantic processing in L2						PAPT ^c
	BNT ^a	SemC ^b	Syn ^b	Ant ^b	Ant II ^b	BAT ^b	BNT ^a	SemC ^b	Syn ^b	Ant ^b	Ant II ^b	BAT ^b	
P1	0.35	0.80	1.00	0.60	0.80	0.80	0.02	0.60	0.00	0.40	0.00	0.25	0.83
P2	0.45	0.80	0.80	1.00	0.80	0.85	0.47	0.40	0.60	0.80	0.60	0.60	0.90
P3	0.18	0.80	0.60	0.60	0.60	0.65	0.42	0.80	1.00	1.00	0.40	0.80	0.92
P4	0.00	0.60 [*]	1.00 [*]	0.00 [*]	0.80 [*]	0.55 [*]	0.00	1.00 [*]	1.00 [*]	0.20 [*]	0.80 [*]	0.60 [*]	0.52 [*]
P5	0.05	1.00	0.40	0.40	0.40	0.55	0.05	0.80	1.00	0.40	0.40	0.65	0.98 [*]
P6	0.07	0.80	0.40	0.60	0.60	0.60	0.52	0.60	0.20	0.60	0.60	0.50	0.87
P7	0.32	0.60	0.60	0.80	1.00	0.75	0.28	0.60	0.60	0.60	0.60	0.60	0.77
P8	0.47	0.60	0.20	0.00	0.40	0.30	0.03	0.00	0.00	0.00	0.00	0.00	0.75
P9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71
P10	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.48
P11	0.47	1.00	1.00	0.00	0.80	0.70	0.05	0.60	0.00	0.00	0.80	0.35	0.83
P12	0.02	0.60	0.20	0.40	0.80 [*]	0.45 [*]	0.00	0.40	0.00	0.40	0.40	0.30	0.90
P13	0.43	0.60	0.20	0.40	0.60	0.45	0.37	0.60	0.40	0.80	0.20	0.50	0.92
P14	0.12	0.60	0.60	0.40	0.40	0.50	0.42	0.80	0.80	0.20	0.40	0.55	0.94
P15	0.20	0.00	0.60	0.40	0.60	0.40	NA [*]	0.00	0.00 [*]	0.80 [*]	1.00 [*]	0.25 [*]	0.52 [*]
P16	0.15	0.40	0.40	0.80	0.00	0.40	0.00	0.00	0.20	0.20	0.60	0.25	0.52
P17	0.42	0.60	1.00	0.00	0.20	0.45	0.03	0.40	0.40	0.00	0.60	0.35	0.73
P18	0.00	0.80	0.60	0.20	0.60	0.55	0.00	0.20	0.60	0.20	0.60	0.40	1.00
P19	0.00	0.80	0.40	0.20	0.00	0.35	0.00	0.20	0.00	0.20	0.60	0.25	0.87
P20	0.63	1.00	1.00	1.00	0.80	0.95	0.67	1.00	1.00	1.00	1.00	1.00	0.98
P21	0.08	0.80	0.20	0.80	0.20	0.50	0.63	1.00	0.80	0.80	0.60	0.80	0.87
P22	0.82	1.00	1.00	1.00	0.80	0.95	0.25	1.00	0.60	1.00	1.00	0.90	0.98
P23	0.18	0.60	0.60	0.40	0.80	0.60	0.15	0.60	0.00	0.00	0.60	0.30	0.63
P24	0.50	0.80	0.40	0.40	0.60	0.55	0.65	0.80	1.00	0.80	0.60	0.80	0.85
P25	0.00	0.40	0.20	0.60	0.20	0.35	0.00	0.20	0.20	0.20	0.20	0.20	0.52
P26	0.70	1.00	1.00	1.00	1.00	1.00	0.80	1.00	1.00	1.00	0.80	0.95	1.00
P27	0.97	1.00	1.00	1.00	0.60	0.90	0.08	1.00	0.20	0.40	0.40	0.50	0.96

Scores represent ^a naming ability, ^b comprehension of spoken words, ^c non-verbal semantic knowledge. Scores below 50% accuracy are presented in bold.

* Values estimated via multivariate imputation by chained equations using the MICE package in R. The L2 BNT score for P15 is marked as NA (not available) because a plausible value could not be estimated using this procedure.

BWA = Bilingual person with aphasia; L1 = native language; L2 = second language; BNT = Boston Naming Test. BAT subtests: SemC= semantic categories; Syn = Synonyms; Ant = Antonyms; Ant II= Antonyms II; BAT = Bilingual Aphasia Test composite score (comprehension of spoken words); PAPT = Pyramids and Palm Trees.

Table 4.

Results of the principal component analyses conducted on the LUQ and the language assessments conducted in each language

LUQ Metrics	PCA on LUQ L1	PCA on LUQ L2
	PC1	PC1
Age of Acquisition (AoA)	-	0.78
Daily Use	0.84	0.72
Family proficiency	0.45	0.82
Educational history	0.86	0.86
Lifetime exposure	0.77	0.95
Lifetime confidence	0.50	0.84
Language Ability Rating	0.82	0.86
% Variance	52.96%	71.14%

Language assessments	PCA on L1 assessments	PCA on L2 assessments
	PC1	PC1
Boston Naming Test (BNT)	0.84	0.88
Bilingual Aphasia Test-composite score (BAT)	0.91	0.93
Pyramid and Palm Trees (PAPT)	0.78	0.79
% Variance	71.80%	74.94%

Factor loadings exceeding .5 are marked in bold.

LUQ= Language Use Questionnaire; PCA = Principal component analysis; L1 =native language; L2 = second language; PC1= Principal component 1.